Did design flaws doom the LHC?

Catastrophic failure that caused accelerator shutdown was not a freak accident, says project physicist.

Running more than a year behind schedule and at half its intended energy, the world's most powerful particle accelerator is slated to begin its first full scientific run this week. Along with relief, the occasion is bringing some soul-searching. One senior scientist who helped to build the Large Hadron Collider (LHC) at CERN, Europe's particle-physics laboratory near Geneva, Switzerland, is claiming that the cause of the delay — a major accident in 2008 — could have been avoided.

"Any technical fault is a human fault," says Lucio Rossi, a physicist who oversaw the production of the accelerator's superconducting magnets. In a paper published on 22 February (L. Rossi *Supercond. Sci. Technol.* **23,** 034001; 2010), he concludes that the catastrophic failure of a splice between two magnets was not a freak accident but the result of poor design and lack of quality assurance and diagnostics. The project, he says, will be coping with the consequences for many months to come.

On 19 September 2008, just weeks before the LHC was first scheduled to start colliding protons, an electrical short caused massive damage. A connection between two superconducting cables developed a small amount of resistance, which warmed the connection until the cables — cooled by liquid helium to superconducting temperatures — lost their ability to carry current. Thousands of amps arced through the machine, blowing a hole in its side and releasing several tonnes of liquid helium. The expanding helium gas created havoc, spewing soot into the machine's ultraclean beamline and ripping magnets from their stands. Repairs took more than a year, and the LHC successfully restarted last November.

"What we have to do is learn from our mistakes and make it better."

An investigation revealed that technicians had not properly soldered the cables together. With tens of thousands of such connections, it is perhaps inevitable that some were faulty, Rossi says, but design flaws worsened the problem. The silver–tin solder that was used melted at high temperatures and did not flow easily into the cable joints. Moreover, workers did not adequately check to see if each connection was electrically secure. Sensors to detect an overheating circuit, which might have helped prevent the accident, were not installed until after it happened.

Worse, says Rossi, when the wires were originally joined, the same silver–tin solder was used to connect them to an adjacent copper stabilizer, meant to provide an escape route for current in the event of a failure. That step risked reheating and destroying the original connection, he says. Making the second connection to the stabilizer with a different type of solder that had a lower melting point could have avoided the problem. Lyn Evans, who oversaw the LHC from 1994 to 2009, says that the idea was considered and rejected because the alternative solder contained lead, a hazard to workers.

A detailed analysis last summer revealed several more bad connections, and CERN now says that it will take a year to correct the problem throughout the machine. As a result, the LHC will not run at its full collision energy of 14 teraelectronvolts (10^{12} eV) until around 2013.

Many LHC scientists involved say that the accident was a natural consequence of constructing such a large and unique machine. "I personally think he [Rossi] is a bit too harsh on himself and the management of the time," says Steve Myers, the current project head of the LHC. "In such a technically complicated project with tight schedules it is almost inevitable that things go wrong."

Pebble-bed nuclear reactor gets pulled

Hopes for the development of pebble-bed nuclear reactor technology, long held up as a safer alternative to conventional nuclear power, have suffered a blow. Last week, the South African government confirmed that it will effectively stop funding a long-term project to develop the technology.

The development company, Pebble Bed Modular Reactor (PBMR), based near Pretoria, says that it is now considering axing three-quarters of its 800 staff, about half of whom are scientists or engineers. "The resources available to the company will not sustain the current cost structure," the company says. The cuts could trigger an exodus of nuclear expertise from South Africa, although some argue that government funding has kept the project going for too long in the face of growing problems.

South Africa started to develop its pebble-bed reactor design in the mid-1990s, hoping that it would deliver cheap electricity and open up a lucrative export industry. It licensed the technology from Germany's Jülich Research Centre, which abandoned a working prototype reactor in 1991 after citing poor business opportunities.

Eskom, South Africa's main electricity generator, based in Johannesburg, set up the PBMR in 1999 to develop the technology into a economically viable reactor. "It caught the mood in South Africa, and the feeling among South Africans was that their technology was as good as anybody's," says Steve Thomas, an energy-policy researcher at the University of Greenwich, London. "This was their chance to show the world what they could do."

PEBBLE BED MODULAR REACTOR (PTY)

Bedtime for pebbles?

The proposed reactor would have used enriched uranium fuel embedded within tennis-ball-sized graphite spheres ('pebbles'). These should enable it to run at temperatures of between 750 °C and 1,600 °C yet resist a core meltdown even if the helium-gas coolant is lost, an attractive safety feature.

But several of the firm's biggest investors, including the utility firm Exelon in Chicago, Illinois, withdrew during the feasibility phase, which ended in 2004. In the four years up to March 2007, the South African government contributed 7.2 billion rands (US$935 million) in funding, on the condition that the PBMR "attract additional investment through investors other than government, and that it secure a customer for its product", according to a government statement. However, despite a revised business model and product offering, the firm has been unable to do either of these, the government says. Funding was last week slashed to 11 million rands over the next three years,

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DINOSAUR BREAKS THE MOULD
Fish-eating spinosaurs not restricted to land.
go.nature.com/xKFewR

M. BRICE/CERN

It took months to repair magnets that were damaged in a major accident to the LHC in September 2008.

But Jim Strait, a physicist at Fermilab in Batavia, Illinois, says that Rossi's analysis is fundamentally right. The connections between the LHC's magnets aren't robust enough, Strait says. "The design looks like one that is optimized to make installation easy," he says. "These stupid little corners [of the design] get short shrift because they are boring." Only constant project reviews and more-integrated management can catch such problems, he says.

Rossi says that he doesn't blame any one person for what happened at the LHC. "In Italian we say, '*Chi non fa, non sbaglia*': 'He who doesn't work makes no mistakes'. What we have to do is learn from our mistakes and make it better." ■

Geoff Brumfiel

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which is "not enough to keep a nuclear design and engineering company going", according to the PBMR.

Runaway costs and technical problems helped to doom the project, says Thomas. "In 1998, they were saying that they would have the demo plant online in 2003" at a cost of 2 billion rands, he says. "The final estimate was that the demo plant would be online in 2018 and it would cost 30 billion rands." Furthermore, he adds, the PBMR has never been held to account for why costs rose every year, why the completion date was continually pushed back or the nature of its design problems.

In a final twist, the PBMR announced last year that it was indefinitely shelving plans to build a demonstration plant. The programme's demise will not help South Africa's goal of doubling its 35,000-megawatt power-generating capacity by 2025.

One problem was that the design became too ambitious, says John Walmsley, past president of the South African branch of the Nuclear Institute, a professional society for nuclear engineers. The PBMR hoped to push the reactor's operating temperature as high as possible to enable not just electricity generation, but also 'process heat' applications such as turning coal into liquid fuels, he says. It also aimed to boost the power output to the very limits of the design to make the reactor more economical. "They tried to build a BMW when they maybe should have started with a Morris Minor," he says.

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Although many scientists had hoped that the safety system of the pebble-bed design would win over opponents of nuclear power, a 2008 report from the Jülich Research Centre cast doubt on those claims, suggesting that core temperatures could rise even higher than the safe threshold.

Tsinghua University in Beijing now hosts the only operational prototype pebble-bed reactor, although similar reactors are being developed in the United States and the Netherlands. But the PBMR's problems are not unique, says Thomas. "Every nuclear nation in the world has had a programme to commercialize this type of reactor, and they all got nowhere." ■

Linda Nordling

German paper chase to end

Sometimes less is more — at least in grant proposals. That's the hope of the DFG, Germany's main research-funding agency, which plans to drastically restrict the number of papers that researchers can list in their grant applications.

From July, someone applying for a year's funding will be able to include only two publications closely related to the proposed project and a maximum of five other papers illustrating their scientific career. The agency hopes that the new rules will help ease the burden on reviewers faced with vast publication lists, and counter the pressure on scientists to publish as many papers as possible in order to win funding or academic appointments. "It is quality, not quantity, which matters," says Matthias Kleiner, president of the DFG.

But some fear that the new rules might deprive reviewers of crucial information, particularly in fields with high publication rates, such as molecular biology. "As a reviewer I am reliant on getting all the information," says Benedikt Grothe, dean of biology at Ludwig Maximilian University in Munich. "And as an applicant I find it dissatisfying not to be able to cite all the papers that I think reviewers should be aware of."

The DFG — which controls an annual budget of more than €2 billion (US$2.7 billion) and funded about half of its 23,000 grant applications last year — is the first funding agency in Europe to cap citations in this way. In the United States, similar rules apply to grants from the National Science Foundation (NSF). But the DFG's plan goes a step further: it will not consider supporting papers that have been submitted to academic journals but not yet accepted for publication. The move aims to counter problems with seemingly impressive publication lists that were brought to light last year when members of a DFG-funded Collaborative Research Centre (SFB) at the University of Göttingen were reprimanded for including unfinished manuscripts in grant applications (see *Nature* 460, 791; 2009). ■

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